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# Chemical composition and quality of water of the Selenga River and its tributaries in Mongolia

Sorokovikova L.M.[1], Tomberg I.V.[1,*], Stepanova O.G.[1], Marinaite I.I.[1], Bashenkhaeva N.V.[1], Khash-Erdene S.[2], Fedotov A.P.[1]

[1] *Limnological Institute, Siberian Branch of the Russian Academy of Sciences, Ulan-Batorskaya Str., 3, Irkutsk, 664033, Russia*
[2] *Mongolian Knowledge Society, kampus Margad, Erdenet 61000, Mongolia*

The chemical composition and current state of water quality of the Selenga River and its tributaries in Mongolia are considered in this article based on the hydrochemical studies carried out in July 2013-2014. The observed changes in the chemical composition of the water resulted from natural and anthropogenic factors are analyzed. It is shown that water quality of the Selenga River and its tributaries worsened because of the entering of polluting components from the catchment area of Ulaanbaatar city and its wastewater. No influence of the wastewater from the Erdenet Ore-Dressing Plant (EODP) on the trace elements content in the water of the Orkhon and Selenga Rivers is revealed.

***Keywords***: chemical composition, water quality, nutrients, petrochemicals, polycyclic aromatic hydrocarbons, trace elements

## 1. Introduction

The Selenga River is the main tributary of Lake Baikal, flowing through the territories of Mongolia and Russia. The length of the river is 1024 km; from its total length, the Selenga flows for 615 km in the territory of Mongolia. Intensive development of natural resources in Mongolia, growth of industry and agriculture increased anthropogenic load on the catchment area of the Selenga River and worsened the quality of its water (Anikanova et al., 1991; Tulokhonov et al., 2009). For example, the world's largest copper-molybdenum deposit being developed by the Erdenet Ore-Dressing Plant and a great number of illicit gold mining sites are located in the watershed of the Selenga River.

As a result, in recent decades, at the boundary with Mongolia, the disorders of the chemical composition of the Selenga River water have been observed; the concentrations of sulphates, nutrients and other components have increased. At the end of the 1990s, the chemical composition of the water was similar to the natural background. For example, sulphate concentrations during the period of open riverbed near the Naushki settlement ranged from 7.5 to 8.5 mg/l (Sorokovikova et al., 2013), while sulphate concentrations continued increasing up to 17.23 mg/l in July, 2018 and up to 20.3 mg/l in 2019. The data obtained during complex international monitoring and the data from the Ministry of Natural Resources of Mongolia (Dolgorsvuren et al., 2012) indicate the increase of the concentrations of sulphates, heavy metals and nutrients in the Selenga River and its tributaries in the territory of Mongolia.

The aim of this work is to investigate the water chemistry of the Selenga River and its major tributaries, and to assess current water quality status.

## 2. Materials and methods

The samples of the water were collected from 20 river stations in July, 2013-2014 (Fig. 1). The samples for chemical analysis were filtered through a membrane filter with a pore size of 0.45 μm. The determination of cations was carried out using the atomic-absorption spectrometry method whose relative error in the determination was 2-3% (Rukovodstvo…, 2009); the determination of anions was carried out using the microcolumn high performance liquid chromatography (HPLC) method. The relative error in the determination of anions by the method did not exceed 5-10% (Baram et al., 1999). The determination of inorganic phosphorus was carried out using the colorimetric method with ammonium molybdate; its relative error was 1.5%. The determination of ammonium nitrogen was carried out using the indophenol method; the relative error was 4-5%. The organic matter content was determined using the dichromate method (Wetzel and Likens, 2003; Rukovodstvo…, 2009). Measured concentrations of the major ions were controlled by the calculating of the error of ionic balance ($R_1$) and the error of the comparison

*Corresponding author.
E-mail address: kaktus@lin.irk.ru (I.V. Tomberg)

of the calculated and measured specific electrical conductivity ($R_2$). The reliability of the obtained results on the concentrations of nutrients was verified by the regular quality control of the analyses within the framework of the EANET international program on the "surface waters" standard samples testing. The concentrations of polycyclic aromatic hydrocarbons (PAH) were measured using chromatography mass spectrometry (Gorshkov et al., 2004). Quantification of individual PAHs (phenanthrene-d10, chrysene-d12 and perylene-l12) was done using "Supelco" standards (USA). The error of the measurements did not exceed 10%. The samples for multielement analysis by ICP-MS were in situ filtered through a membrane filter with a pore size of 0.45 μm. The samples were analyzed using quadrupole mass spectrometer Agilent 7500e.

## 3. Results and discussion

### 3.1. Ion composition of water

The chemical composition of the Selenga River over the entire territory of its basin is formed under similar geological and climatic conditions that could explain its low variability along the river. The Selenga River waters and its tributaries along the entire length are characterized as being a hydro-carbonate calcium type. It was found out that the total content of the major ions in the Selenga River increased from 199.8 to 237.4 mg/l in the upper reaches of the river (between the stations 1 and 2) (Fig. 2). However, the concentrations of ions decreased to 206.9 mg/l (the Naushki settlement, Russian-Mongolian boundary) due to the dissolving of the Selenga River by the tributaries. In the tributaries of the Selenga River the highest content of ions was observed in the Khainun River (Table 1), however, this river did not significantly affect the chemical composition of the Selenga River water (Fig. 2) due to its low water budget. The obtained data showed that the Orkhon River mostly influenced the Selenga River water quality.

The study of the Orkhon River carried out in July 2014 showed that the total content of the major ions in the water ranged from 131.3 to 163.3 mg/l. The concentrations of ions in the Orkhon tributaries varied by an order or more (Table 1). Thus, the highest concentrations of ions and their sum were observed in the Burgalta and Khangal Rivers (Table 1). As a result, the highest content of ions is observed downstream of the inflow point of the Burgalta and Khangal Rivers. This fact could be related to the effect made by the wastewater from the Erdenet Ore-Dressing Plant.

However, most ecological problems are determined in the Tuul River below Ulaanbaatar. For example, the sum of ions and chlorine-ions increases 2 and 14 times, respectively, in comparison to their concentrations in the river reaches above the city (Table 1).

The inflow of the low mineralized water of the Eroo River causes the decrease of the sum of ions and sulphates in the Orkhon River. Despite the fact that the inflow of the Orkhon River increases the concentrations of sulphates, chlorides and sodium in the Selenga River.


**Fig. 1.** Map of the sampling locations in 2013-2014.
1 – the Selenga River downstream of the confluence point of the Ider and Muren Rivers; 2 – the Selenga River upstream of the Khanuin River; 3 – the Khanuin River; 4 – the Selenga River upstream of the Egyin River; 5 – the Egyin River; 6 – the Selenga River downstream of the Egyin River; 7 –the Selenga River upstream of the Orkhon River; 8 – the Eroo River; 9 – the Tuul river upstream from Ulaanbaatar; 10 – the Tuul River downstream from Ulaanbaatar; 11 – the Orkhon River upstream from the Bulgan settlement;12 – the Orkhon River downstream from the Bulgan settlement; 13 – the Khangal River; 14 – the Burgalta River; 15 – the Borun-Buren River; 16 – the Orkhon River downstream of the Kharaa River; 17 – the Kharaa River; 18 – the Orkhon River downstream of the Eroo River; 19 – the Orkhon River downstream of the Eroo River; 20 – the Selenga River (Naushki).

**Table 1.** The sum of ions and the concentration of major ions (mg/l) in the tributaries of the Selenga River in the territory of Mongolia. Numbers of sampling stations are shown according to Fig. 1

| Sampling location | Sum of ions | $Na^+$ | $K^+$ | $Ca^{2+}$ | $Mg^{2+}$ | $Cl^-$ | $SO_4^{2-}$ | $HCO_3^-$ |
|---|---|---|---|---|---|---|---|---|
| Tributaries of the Selenga River, 2013 | | | | | | | | |
| 3 (the Khanuin River) | 318.6 | 27.2 | 1.9 | 32.7 | 15.0 | 3.6 | 19.9 | 218.4 |
| 5 (the Egyin River) | 200.0 | 3.9 | 1.4 | 34.4 | 7.4 | 0.63 | 16.3 | 136.0 |
| 19 (the Orkhon River) | 188.6 | 11.7 | 1.8 | 25.9 | 6.9 | 5.1 | 16.4 | 120.8 |
| Tributaries of the Orkhon River, 2014 | | | | | | | | |
| 9 (the Tuul River) | 47.6 | 2.1 | 0.76 | 8.2 | 1.1 | 0.3 | 4.6 | 30.5 |
| 10 (the Tuul River) | 93.3 | 6.5 | 1.68 | 14.2 | 2.2 | 4.4 | 10.6 | 53.7 |
| 13 (the Khangal River) | 808.2 | 55.0 | 7.90 | 103.0 | 36.0 | 37.2 | 272.7 | 296.5 |
| 14 (the Burgalta River) | 714.3 | 52.1 | 4.63 | 101.6 | 32.0 | 26.0 | 242.9 | 255.0 |
| 15 (the Borun-Buren River) | 235.1 | 9.8 | 1.23 | 36.0 | 10.0 | 1.5 | 10.6 | 165.9 |
| 17 (the Kharaa River) | 215.2 | 12.5 | 1.99 | 30.6 | 8.8 | 4.6 | 18.9 | 137.9 |
| 8 (the Eroo River) | 93.6 | 3.7 | 1.2 | 14.7 | 3.0 | 0.67 | 6.2 | 64.1 |
| MAC level for drinking water | 1000 | 200 | - | - | - | 350 | 500 | - |
| MNS 4586-98 | | | | | | 300 | 100 | |

### 3.2. Nutrients and organic matter

Nutrient concentrations in the studied rivers ranged widely. The content of ammonium nitrogen along the Selenga and Orkhon Rivers was almost equal in both rivers and ranged from 0.01mg to 0.03 mg N/l. The concentrations of nitrate nitrogen differed considerably; in the Selenga River, the concentrations ranged from 0.04 to 0.13 mg N/l, in the Orkhon River – from 0.23 to 0.48 mg N/l, reaching their maximum values downstream of the inflow of the Kharaa River. The concentration of nitrite nitrogen in these rivers did not exceed 0.003 mg N/l. In July 2013-2014, the total of mineral nitrogen in the Selenga River did not exceed 0.14 mg N/l before the inflow point of the Orkhon River, and was 0.13 mg N/l below the confluence (the Naushki settlement).

In the water of the tributaries, the concentrations of nitrogen considerably exceed those of the Selenga and Orkhon Rivers. The highest values are observed in the Khangal, Burgalta and Tuul Rivers downstream from Ulaanbaatar (Table 2). It could be related to the influence of agricultural fields and livestock farms due to the presence of high concentrations of nitrite nitrogen.

During the observation period, the concentrations of mineral phosphorus were 7-8 µg P/l in the upper reaches of the Selenga River (between the stations 1 and 2), while total phosphorus was 162-170 µg P/l (Table 2, Fig. 3a). We suppose it is due to the intensive agricultural development, including livestock farms, and due to the entering of phosphorus from the catchment area. Downstream the Selenga River, within the Mongolian section, the content of total phosphorus decreases and does not exceed 92 µg P/l, the content of mineral phosphorus does not exceed 10 µg P/l.

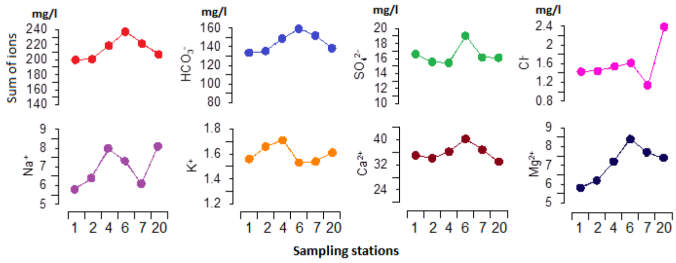


**Fig. 2.** Spatial dynamics of the concentrations of major ions in the Selenga River and its tributaries, 2013. Numbers of sampling stations are shown according to Fig. 1

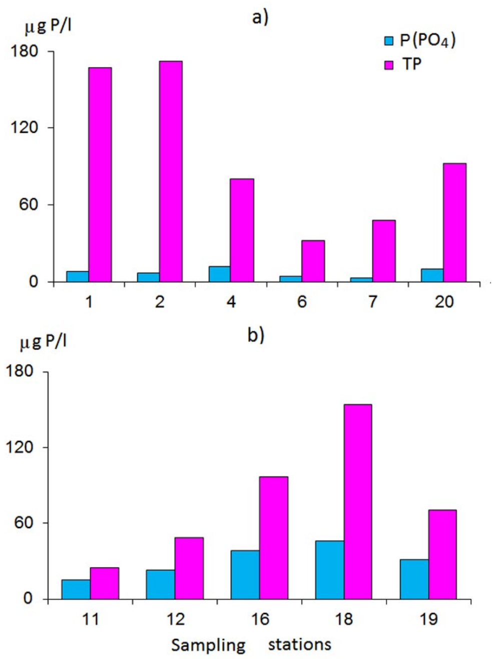


**Fig. 3.** Changes of the concentrations of phosphate (1) and total phosphorus (2) in the Selenga (a) and Orkhon (b) Rivers. Numbers of sampling stations are shown according to Fig. 1

**Table 2.** The dynamics of the nutrient concentrations in the tributaries of the Selenga and Orkhon Rivers, July 2013-2014. Numbers of sampling stations are shown according to Fig. 1

| Sampling location | $NH_4^+$ | $NO_2^-$ | $NO_3^-$ | $P_{min.}$ | $P_{tot.}$ | $C_{org.}$ |
|---|---|---|---|---|---|---|
| | mg N/l | | | µg P/l | | mg C/l |
| The Selenga River, 2013 | | | | | | |
| 1 | 0.03 | 0.002 | 0.09 | 8 | 162 | 2.6 |
| 2 | 0.01 | 0.002 | 0.13 | 7 | 172 | 2.4 |
| 4 | 0.01 | 0.002 | 0.10 | 12 | 80 | 2.8 |
| 6 | 0.01 | 0.001 | 0.11 | 4 | 32 | 4.1 |
| 7 | <dl | 0.002 | 0.04 | 3 | 48 | 3.6 |
| 20 | <dl | 0.002 | 0.10 | 10 | 92 | 3.6 |
| Tributaries of the Selenga River, 2013 | | | | | | |
| 3 (the Khainun River) | 0.01 | 0.001 | 0.03 | 6 | 35 | 3.0 |
| 5 (the Egyin River) | 0.01 | 0.001 | 0.06 | 2 | 8 | 4.1 |
| 19 (the Orkhon River) | <dl | 0.002 | 0.27 | 43 | 212 | 5.3 |
| The Selenga River, 2014 | | | | | | |
| 7 | 0.02 | 0.003 | 0.12 | 12 | 17 | 6.8 |
| 20 | 0.02 | 0.002 | 0.11 | 6 | 82 | 5.9 |
| The Orkhon River, 2014 | | | | | | |
| 11 | 0.02 | 0.002 | 0.24 | 15 | 71 | 13.6 |
| 12 | 0.03 | 0.003 | 0.23 | 23 | 82 | 5.1 |
| 16 | 0.02 | 0.002 | 0.43 | 38 | 147 | 14.2 |
| 18 | 0.03 | 0.002 | 0.48 | 46 | 154 | 6.0 |
| 19 | 0.03 | 0.002 | 0.33 | 31 | 77 | 6.3 |
| Tributaries of the Orkhon River, 2014 | | | | | | |
| 9 (the Tuul River) | 0.02 | 0.002 | 0.06 | <dl | 32 | 6.3 |
| 10 (the Tuul River) | 0.20 | 0.050 | 0.40 | 72 | 101 | 11.4 |
| 13 (the Khangal River) | 0.15 | 2.557 | 10.02 | 26 | 209 | 4.9 |
| 14 (the Burgalta River) | 0.00 | 0.129 | 5.52 | 161 | 163 | 5.1 |
| 15 (the Borun-Buren River) | 0.03 | 0.002 | 0.05 | 26 | 32 | 4.3 |
| 17 (the Kharaa River) | 0.03 | 0.003 | 0.40 | 38 | - | 6.5 |
| 8 (the Eroo River) | 0.03 | 0.002 | 0.05 | 1 | 15 | 8.2 |
| MNS 4586-98 | - | - | - | - | 100 | - |

dl – detection limit

In some tributaries, the concentrations of both mineral and total phosphorus are considerably higher than those are in the Orkhon River (Table 2). It is supposed to be related to the intensive anthropogenic load on their catchment areas and to the low water level. The highest phosphorus concentrations are observed in the Orkhon River tributaries, the Burgalta, Khangal and Tuul Rivers, downstream from Ulaanbaatar. The lowest concentrations were in the Tuul River upstream from Ulaanbaatar and the Eroo River.

Tributaries water inflows, enriched with phosphorus species, result the increase of the concentrations in the Orkhon River. The spatial variations of the concentrations of mineral and total phosphorus in the Orkhon River are shown in Fig. 3b. As can be seen in the figure, from the upper reaches to the mouth of the Orkhon River, the phosphorus concentrations gradually increase and then decrease downstream of the inflow of the Eroo River. The phosphorus concentration in the Selenga River varies depending on the total phosphorus content in the upper reaches of the Orkhon River. Thus, in the Orkhon River, it was 212 µg P/l, in the Selenga River near the Naushki settlement, it was 92 µg P/l in 2013 (Table 2).

According to the Mongolian water quality standards (Mongol ulsyn snadart, 1999), the content of phosphorus in water should not exceed 100 µg P/l. As can be seen from the obtained data on the Burgalta, Khangal and Tuul Rivers, the content of phosphorus exceeds the maximum allowable concentrations.

The content of organic carbon in the rivers ranged from 2.4 to 14.2 mg C/l. The increased content of organic matter was reported below the inflow of the Tuul River downstream from Ulaanbaatar (Table 2). The increase of the concentrations of organic carbon in the Tuul River in the reach downstream from Ulaanbaatar points to the intensive anthropogenic load on the river's ecosystem and to the low water quality.

### 3.3. Petrochemicals and polycyclic aromatic hydrocarbons (PAHs)

The content of petrochemicals in the Orkhon River along its entire length and in its tributaries was low, <0.005-0.017 mg/l (Table 3). The concentrations were slightly increased in the Tuul River downstream from Ulaanbaatar and in the Khangal River downstream from the Ore-Dressing Plant.

PAHs are important water quality indicators, classified as persistent organic pollutants having mutagenic and cancerogenic characteristics (Menzie and Potokib, 1992). The content of the sum of sixteen PAHs in the Orkhon River ranged from 6.5 to 34 ng/l (Table 4). The increased content of PAHs was observed in the Tuul (downstream from Ulaanbaatar) and Khangal Rivers. So-called “light” PAHs (naphthalene, acenaphthylene, fluorine, phenanthrene, anthracene, fluoranthene) make the major contribution to the sum of PAHs. The concentrations of the “heavy” PAHs (benz[a]anthracene, chrysene, benz[b]fluoranthene, benz[k]fluoranthene, benz[a]pyrene, indeno[1,2,3-c,d]pyrene, benz[g,h,i]perylene, bibenz[a,h]anthracene) are found out at the sensitivity level of the used method. The concentrations of benz[a]pyrene and naphthalene were lower than the ones regulated by the Russian state standards for drinking and natural waters (Prikaz…, 2018; SanPin 2.1.4.1074-01, 2018).

For instance, European Environmental Agency monitors the total content of six PAHs (benz[a]pyrene, benz[b]fluoranthene, benz[k]fluoranthene, benz[g,h,i]perylene, indeno[1,2,3-c,d]pyrene) and their total concentration in drinking water should not exceed 110 ng/l (Council directive, 1998). The concentration of the six PAHs in the Selenga River also was <200 ng/l.

In general, the concentrations of the sum of PAHs in the Orkhon River were low. For example, the sums of PAHs were 910-1520 ng/l in the Aodjang River (China) (Li et al., 2010), 4.2 -310 ng/l in the Olkha River (East Siberia, Russia) (Marinaite et al., 2013), and 78 -159 ng/l in the delta of the Selenga River in spring (Marinaite, 2010).

**Table 3.** The content of petrochemicals (mg/l) in the Orkhon River and its tributaries in the territory of Mongolia, July 2014. Numbers of sampling stations are shown according to Fig. 1.

| Sampling stations | C, mg/l |
|---|---|
| 7 | 0.007 |
| 8 | 0.006 |
| 9 | 0.007 |
| 10 | 0.011 |
| 11 | <dl |
| 12 | 0.006 |
| 13 | 0.017 |
| 14 | 0.008 |
| 15 | 0.005 |
| 16 | 0.005 |
| 17 | 0.006 |
| 18 | 0.005 |
| 19 | 0.006 |
| 20 | 0.008 |

dl – detection limit

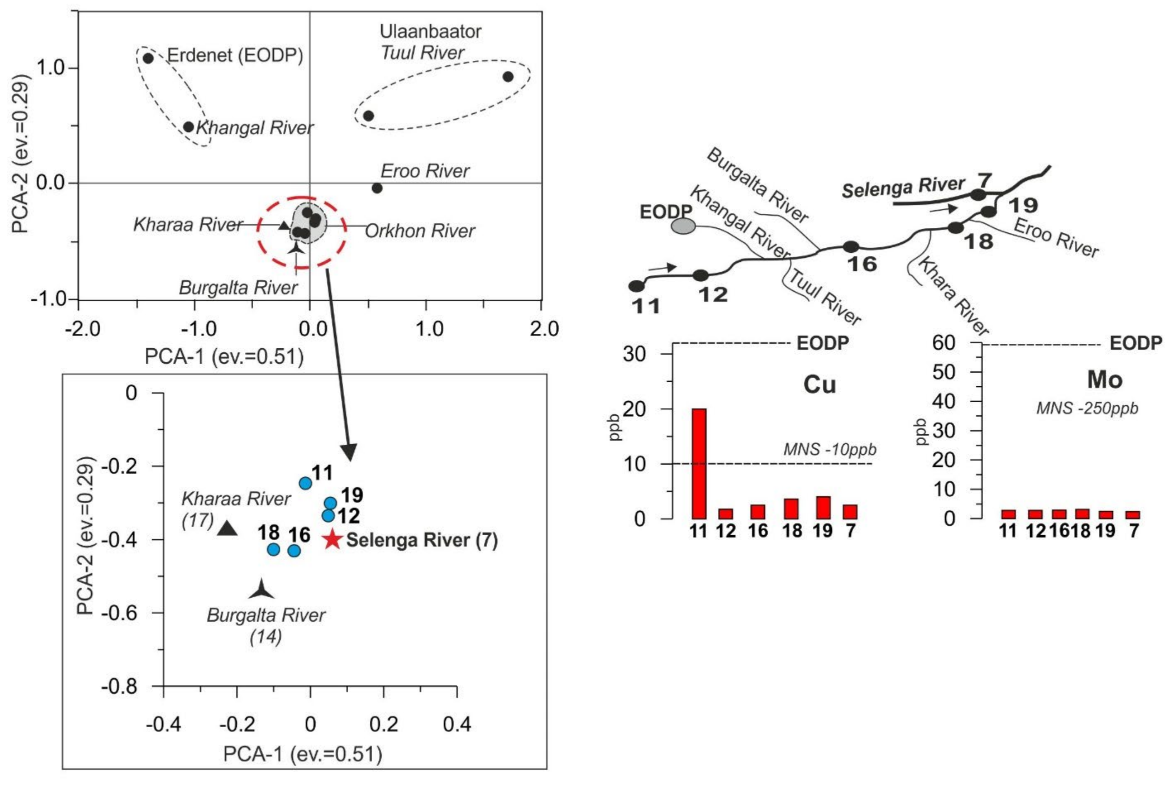


**Fig. 4.** Trace elements areas of the studied watershed of the Orkhon River based on PCA.

**Table 4.** The content of PAHs (ng/l) in the Orkhon River and its tributaries and in The Selenga River. July 2014. Numbers of sampling stations are shown according to Fig. 1.

| Components | Sampling stations | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| Naphtalene | 4.1 | 3.5 | 3.3 | 4.5 | 2.3 | 5.3 | 9.3 | 4.3 | 4.1 | 5.4 | 3.2 | 3.6 | 3.9 | 6.2 |
| Acenaphthylene | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl |
| Acenaphtene | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl |
| Fluorene | 0.6 | 0.5 | 0.4 | < dl | 0.5 | 0.9 | < dl | 2.1 | 2.1 | 0.6 | 0.7 | 0.4 | 0.5 | 0.9 |
| Phenanthrene | 1.9 | 1.6 | 1.5 | 12 | 0.6 | 2.1 | 17 | 2 | 1.9 | 2.7 | 2.0 | 1.7 | 1.7 | 2.5 |
| Anthracene | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl | < dl |
| Fluoranthene | 0.5 | 0.5 | 0.6 | 2.5 | 0.2 | 0.7 | 3.7 | 0.6 | 0.6 | 0.3 | 0.5 | 0.4 | 0.5 | 0.7 |
| Pyrene | 0.7 | 0.7 | 0.8 | 3.7 | 0.3 | 0.8 | 3.5 | 0.7 | 0.5 | 0.3 | 0.6 | 0.6 | 0.7 | 0.9 |
| Sum of PAHs | 7.8 | 6.8 | 6.5 | 23 | 3.9 | 10 | 34 | 10 | 9.2 | 9.3 | 7.0 | 6.7 | 7.3 | 11 |

dl – detection limit

### 3.4. Trace elements in water

The trace element composition of the studied watershed of the Orkhon River can be divided into three areas by Principal component analysis (PCA) (Fig. 4). The first area – the Tuul River near Ulaanbaatar, the second area – the area near the EODP and the Khangal River, and the third area includes the Orkhon, Selenga, Kharaa and Burgalta Rivers. In wastewaters from the sludge storage pits of the EODP, the concentrations of copper and molybdenum exceeded the MAC level set by the Russian and Mongolian standards for natural waters. However, 70 km downstream the Orkhon River from the EODP, the concentrations of copper and molybdenum in the river were close to the values characteristic for the upper reaches of the Orkhon River. In addition, the microelement composition of the Selenga River before the confluence with the Orkhon River is similar to the microelement composition in the lower reaches of the Orkhon River (Fig. 4).

While the microelement content of the Eroo River differs from the content of other tributaries of the Orkhon River, it was not found out that the Ore-Processing Mill of Darkhan affected the microelement composition of the Eroo and Orkhon Rivers. In general, it is most likely that there was no significant influence of these tributaries on the elemental composition of the Orkhon River.

## 4. Conclusions

The chemical composition of the Selenga River and its tributaries was studied in 2013-2014. It was found out that the concentrations of sulphate increased up to 16-16 mg/l as compared with the beginning of the 2000s. As can be seen from the obtained data, the content of phosphorus in the Burgalta, Khangal and Tuul Rivers exceeds the maximum allowable concentrations set by the Mongolian water quality standards. On the contrary, the content of total phosphorus in the Selenga River at the site the Khanuin River – Naushki did not exceed the maximum allowable concentrations. The concentrations of benz[a]pyrene and naphthalene were lower than the ones set by the Russian state standards for drinking and natural waters. The elemental composition of the studied rivers is quite similar within the inter-annual aspect. It was not found out that the EDOP and the Ore-Processing Mill of Darkhan affected the microelement composition of the Orkhon and Eroo Rivers.

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